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## The Effect of Volute Tongue and Passage Configuration On The Performance of Centrifugal Fan

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### ABSTRACT

The performance and flow stability of centrifugal fans is influenced considerably by the design of the volute passage and tongue at the re-circulation port. In this study the performance of a fan in conjunction with four alternative volute designs has been investigated. The alternative volutes include a modified passage design and the application of a rounded tongue leading edge at the re-circulation port. The effect of these volute configurations on the fan and volute performance was examined by the precise measurement of flow at volute inlet and near the volute tongue. From the test results it was found that the modified volute designs led to an improvement in fan performance, however the onset of flow instability occurred at increased flow rates.

### INTRODUCTION

A spiral shaped volute which collects the flow from the diffuser and passes it to a single discharge pipe is a basic component of centrifugal compressors and fans. Assessment of the design and performance of the collecting volute has received only limited investigation. The volute is usually designed through the application of a one-dimensional analysis assuming a free vortex flow from the volute inlet to the centre of the volute passage, Eck(1). The design objective is to achieve a uniform flow at volute inlet. This is usually attained at the design flow rate only; at off-design conditions a pressure gradient develops circumferentially around the volute passage. At low flow rates, the pressure increases with azimuth angle while at high flow rates the pressure decreases. The pressure distortions reduce the stage performance and have a direct impact on diffuser and impeller flow stability.

To maintain constant flow angle with azimuth angle, a re-circulating flow port at the volute tongue is usually adopted. Miyanaga et al.(2) showed that the design of the leading edge of the re-circulating flow port has a significant impact on volute performance at high flow rate. A rounded tongue reduced the degree of flow separation and the magnitude of the following wake in the discharge duct.

Yao et al.(3) proposed a design procedure that no longer considered the flow angle at volute inlet to be constant. This approach was further developed by Qi et al.(4) and allows alternative volute profiles to be developed by varying the volute inlet flow angle with azimuth angle. Dilin et al.(5) applied this procedure to re-design a turbocharger volute and assessed its potential theoretically.

By applying the above-mentioned procedure which applied a high flow angle at small azimuth angles, a modified fan volute was designed and tested. The test results are compared to the fan volute designed through the conventional design concept of Eck. Also both volute designs were modified to include a re-circulating port which accommodated a rounded tongue leading edge. Through this experimental study the merits and demerits of the alternative volute designs on the flow stability and performance improvement are clarified.

### NOTATION

$\psi$ : Pressure coefficient	$\psi = p_s / (\rho u^2)$	$\phi$ : Flow coefficient	$\phi = c_{m2} / c_{u2}$
$C_p$ : Pressure recovery coefficient	$C_p = (p_{sa} - p_{sb}) / p_{db}$	$\xi$ : Loss coefficient	$\xi = (p_{tb} - p_{ta}) / p_{db}$
$p_s$ : Static pressure		$p_t$ : Total pressure	
$p_d$ : Dynamic pressure	$p_d = \rho c^2 / 2$	$\rho$ : Density of fluid	
$u$ : Peripheral velocity of volute inlet		$c_m$ : Meridian component of velocity	

$c_u$ : Tangential component of velocity  
 b: Width of diffuser passage

d: Diameter of impeller

Subscripts

0: Impeller inlet  
 2: Volute inlet

1: Diffuser inlet  
 3: Volute exit

## APPARATUS AND INSTRUMENTATION

The test facility is shown in Fig.1-a and Fig.1-b. The air was supplied from a radial impeller through a vaneless diffuser. In this investigation, the rotational speed of the impeller was fixed at 3000 rpm with rotational speed accuracy of  $\pm 1.0\%$ . The basic design specification of impeller and diffuser are as follows:

Diameter of impeller inlet	$d_0=157\text{mm}$
Diameter of impeller exit	$d=270\text{mm}$
Number of blades	12
Width of diffuser passage	$b_2=17.6\text{mm}$
Diameter of diffuser inlet	$d_1=270\text{mm}$
Diameter of volute inlet	$d_2=540\text{mm}$

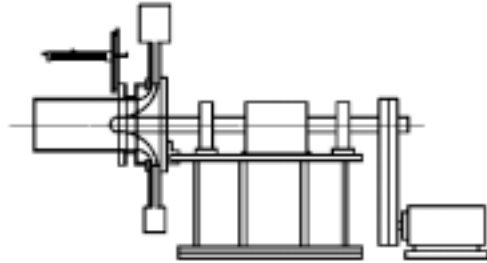


Fig.1-a General arrangement of experimental facility

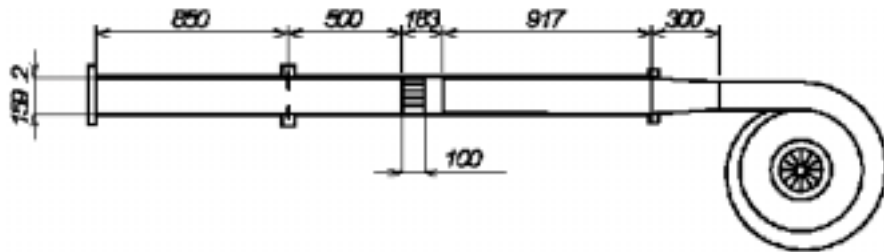


Fig.1-b General arrangement of experimental facility

In this investigation four volutes with a rectangular cross section, with a breadth to height ratio of 0.8, were tested. The conventional design, which assumed that the flow leaving the vaneless diffuser was uniform in the circumferential direction, is referred to as EA. The modified volute designs are then:

EA: Basic type of volute which was designed using the free vortex procedure.

ER: Same design as EA, but this type has a modified volute tongue with a rounded leading edge.

MA: A modified passage design, which applied a large flow angle at small azimuth angles.

MR: Same design as MA, but this type has a modified volute tongue with rounded leading edge.

The design inlet flow angle for the modified passage design, volute M, is shown in Fig2.

The detailed internal flow in the diffuser and volute passage near the tongue was measured with a three-hole yaw probe connected to multi-point pressure scanning system with a pressure range of  $\pm 2.5$  kPa and an accuracy of  $\pm 0.20\%$ . Flow angle, pressure and velocity were obtained by mass flow averaging the three-hole yaw probe traverse measurement data. Measurement points were located at 12 circumferential positions at diffuser inlet, 22 circumferential positions at diffuser outlet, and 9 positions in the volute passage near the tongue. Yaw probe traverse measurements were made at 9 axial positions for each location point. The location of these traverse positions is shown in Fig.3.

Static pressure recovery and total pressure loss were normalized by the dynamic pressure. To evaluate the flow coefficient at volute inlet a free vortex flow was assumed through the vaneless diffuser.

A FFT analyzer was applied to analyze the pressure fluctuations in the diffuser. Two pressure transducers were attached at azimuth angles of 0 and 90 degrees, at diffuser inlet, and connected to the FFT analyzer.

Silk thread tufts, with dandelion seed heads attached, were used to visualize the flow in the volute and diffuser passage. The dandelion seed heads were attached at the top of the thread to follow the flow direction as shown in Fig.4. The location of the tuft installation points is shown in Fig.5. To film the behavior of the tufts a high-speed video was used at a shutter speed of 1/1000 second. A trace capability of over 400 Hz fluctuation was verified for the tufts by the high speed video image.

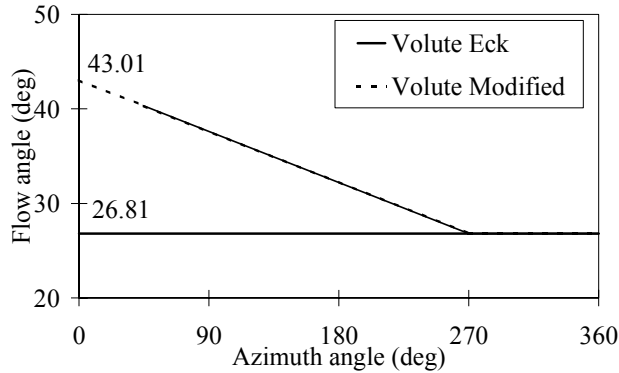


Fig.2 Design flow angle

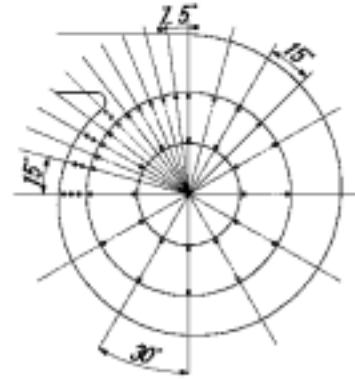


Fig.3 Locations of traverse measurement

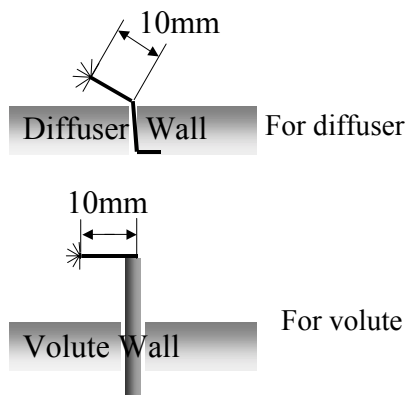


Fig.4 Tuft with dandelion seed head

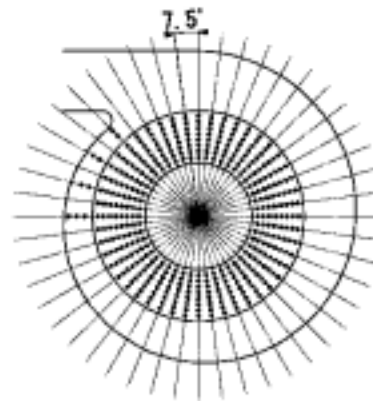


Fig.5 Tuft insert locations

## RESULTS AND DISCUSSION

### Consideration of Performance Improvement

The performance of the fan, with the alternative volute designs, is presented in terms of the pressure coefficient as a function of the flow coefficient,  $cm^2/cu^2$ , in Fig.6. Incipency (Onset) of diffuser rotating stall is shown in the enlarged plot in Fig.6a. From this figure it can be seen that with volute design MR the fan showed a high pressure coefficient compared with the other volutes except at low flow coefficients. From the enlarged figure, Fig.6a, in the peak flow coefficient region, it can be seen that the incipency of rotating stall for the conventional design EA and ER occurred at a smaller flow coefficient than that with the modified passage design MA, and MR.

Fig. 7 and 8 show the volute performance in terms of the pressure recovery coefficient and total pressure loss coefficient as a function of flow coefficient. The volute inlet conditions were evaluated by mass flow averaging the traverse measurement values of the yaw probe at the diffuser exit. In these figures, data in the unstable diffuser rotating stall region were eliminated because the evaluated values were not meaningful due to the fluctuation of pressure and flow direction. In the high flow region the modified volute design (MR) provided the dominant pressure recovery coefficient and total pressure loss coefficient when compared with the conventionally designed volute. The Improvement in performance was small in the low flow region. Similar

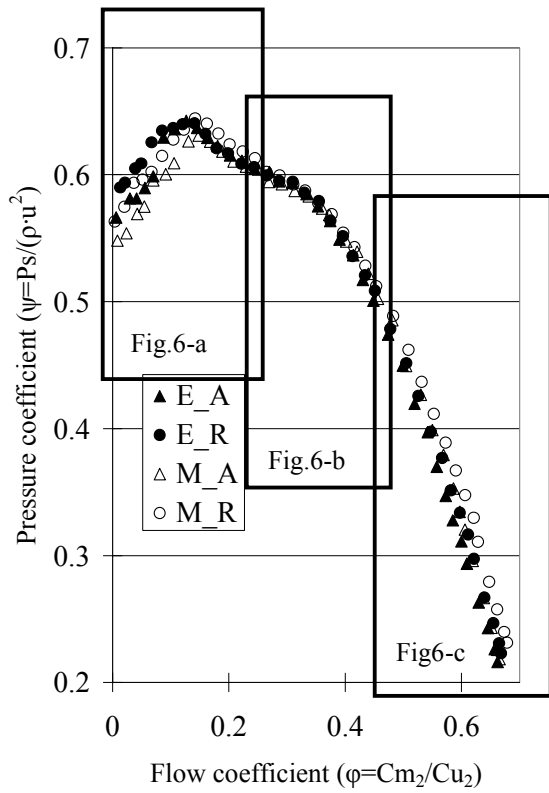


Fig.6 Fan performance characteristics

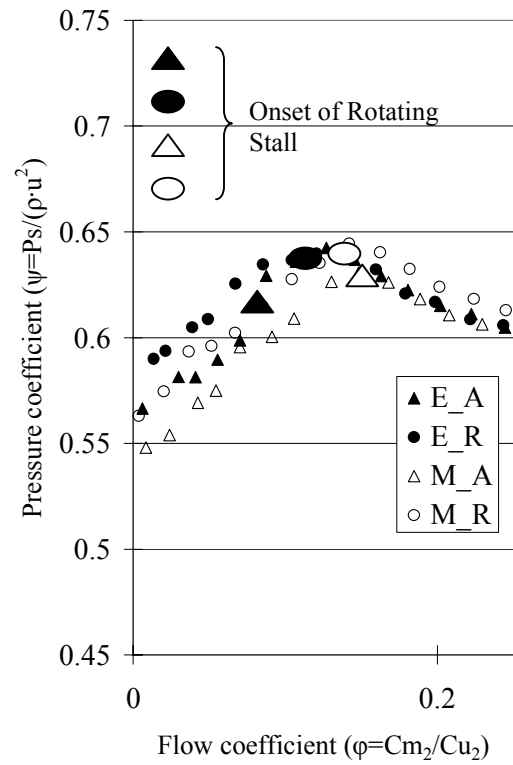


Fig.6-a Fan performance characteristics (Low flow coefficient)

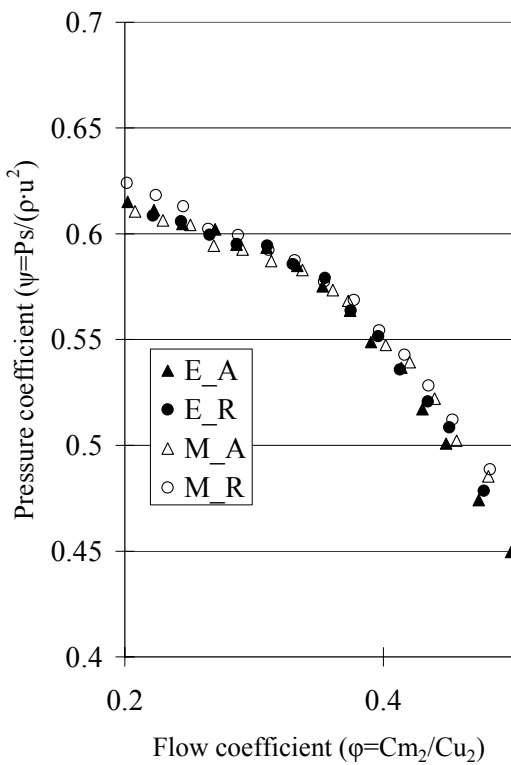


Fig.6-b Fan performance characteristics (Medium flow coefficient)

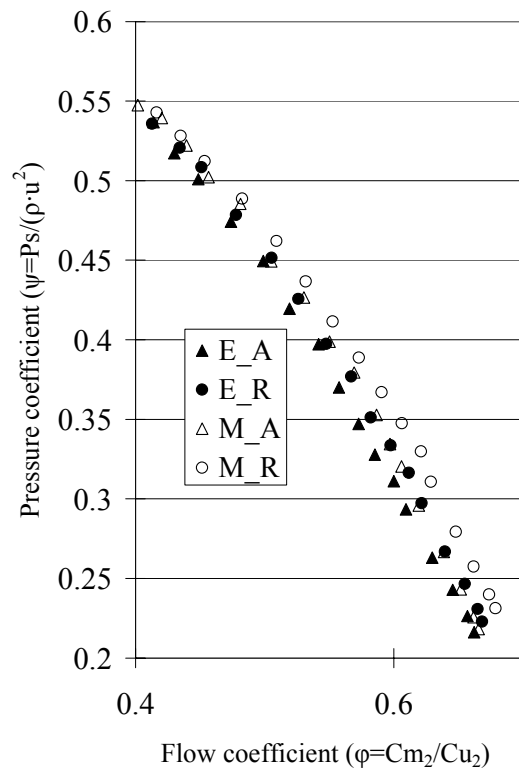


Fig.6-c Fan performance characteristics (High flow coefficient)

results were obtained for the performance of the volute and diffuser i.e. from diffuser inlet to volute exit, Fig.9 and 10. Performance improvement by adoption of a re-circulating port is clearly seen in the comparison of EA, ER and MA, MR.

For the low flow region with a positive gradient of pressure coefficient, volute ER showed a higher pressure coefficient than that with Type MR. The inclusion of the stability of flow will be discussed later.

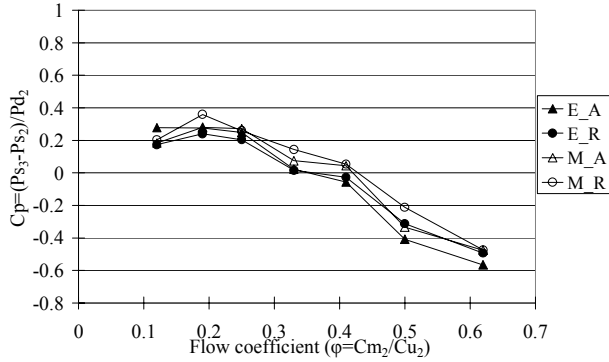


Fig.7 Pressure recovery coefficient of volute

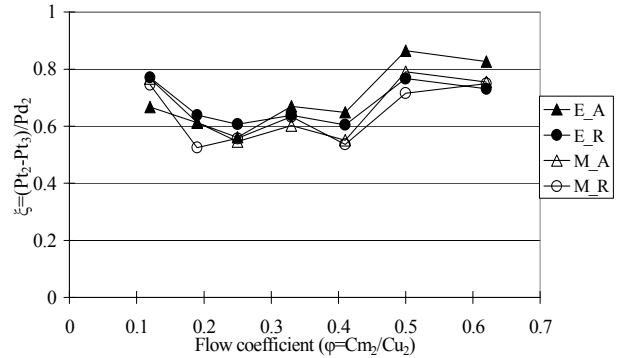


Fig.8 Loss coefficient of volute

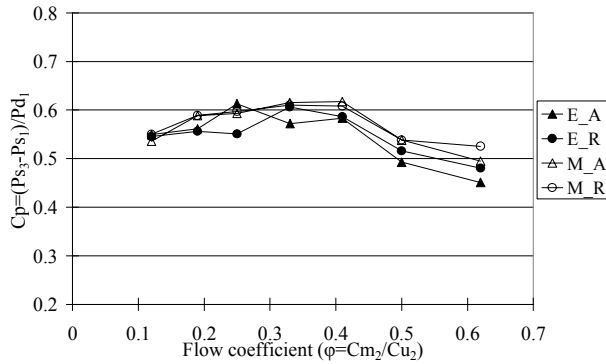


Fig.9 Pressure recovery coefficient from diffuser inlet to volute exit

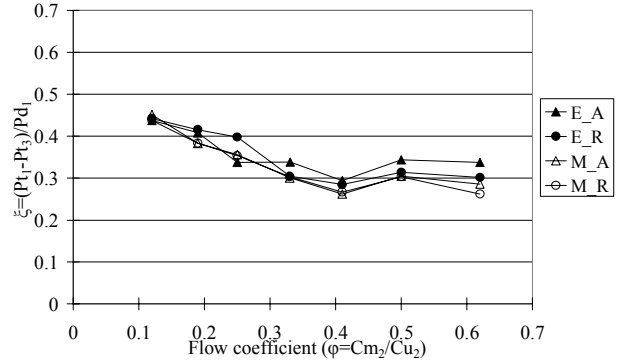


Fig.10 Loss coefficient from diffuser inlet to volute exit

A comparison of flow angle, absolute velocity and static pressure as a function of azimuth angle is shown in Fig.11 for the four volute designs, at flow coefficients of 0.19, 0.41 and 0.62.

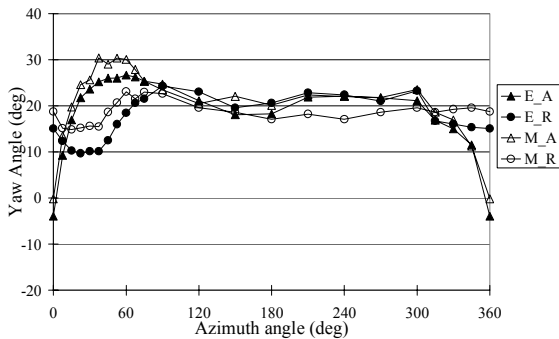


Fig.11-a-1 Flow angle at volute inlet (Flow coeff.=0.19)

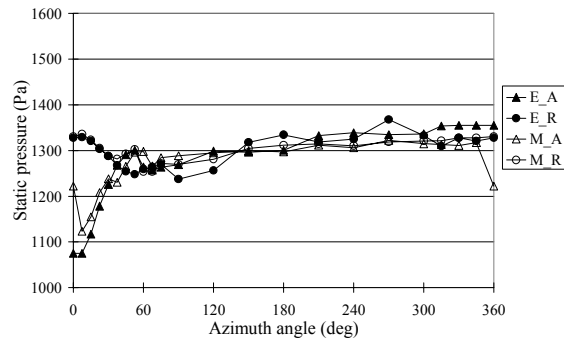


Fig.11-b-1 Static pressure at volute inlet (Flow coeff.=0.19)

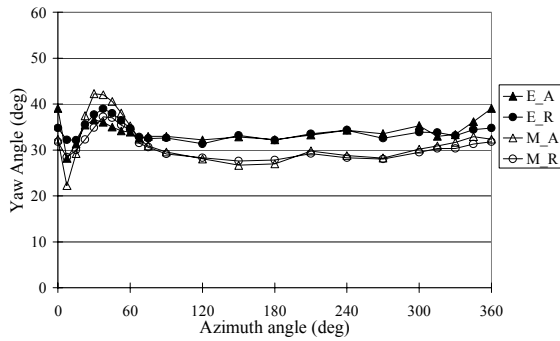


Fig. 11-a-2 Flow angle at volute inlet  
(Flow coeff.=0.41)

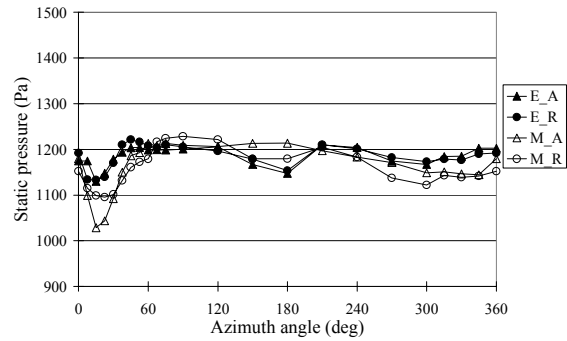


Fig. 11-b-2 Static pressure at volute inlet  
(Flow coeff.=0.41)

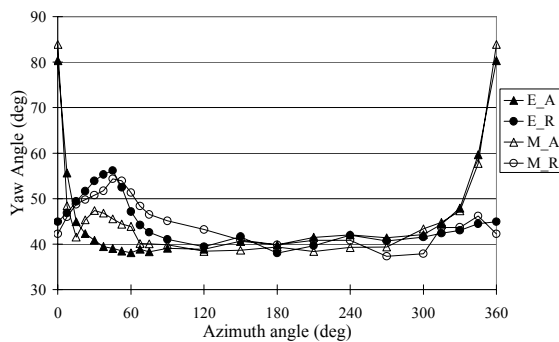


Fig. 11-a-3 Flow angle at volute inlet  
(Flow coeff.=0.62)

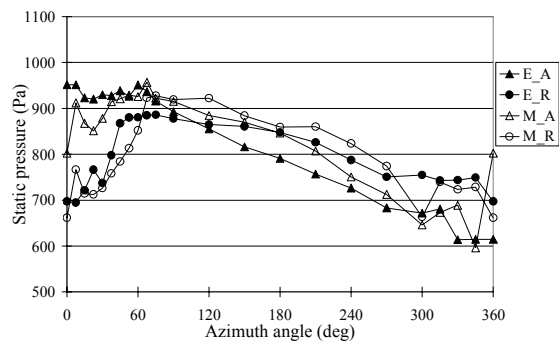


Fig. 11-b-3 Static pressure at volute inlet  
(Flow coeff.=0.62)

As expected from the design procedure volute designs MA and MR show a high flow angle at small azimuth angles. For the flow coefficient of 0.19 the volutes without a re-circulating port, Designs EA and MA, show a stepwise reduction in flow angle and decrease in static pressure in the vicinity of the tongue. In this case the volute inlet flow direction was nearly circumferential. For the volute with a re-circulating port and rounded tongue, this deviation is eliminated and volute MR showed the most favorable distribution of flow angle and pressure. For a flow coefficient of 0.41 the flow angle and static pressure deviation with azimuth angle was small compared to that observed at a flow coefficient of 0.19. At the high flow coefficient of 0.62 a near radial flow is shown at the tongue for the volutes without a re-circulating port. This will lead to separation from the edge of volute tongue, as predicted by Pan et al(5). By adopting a rounded tongue leading edge the flow distribution near the volute tongue was improved, as shown in Fig.11. In addition the pressure recovery coefficient and total pressure loss coefficient was improved by the application of a rounded tongue.

### Consideration of Flow Stability

The pressure fluctuations of rotating stall were detected by pressure transducers installed at two stations at the diffuser inlet, 90 degrees apart. The frequency spectra of the pressure fluctuations, obtained by the FFT analyzer, are shown in Fig.12. The peak seen near 20 Hz for all designs is due to diffuser rotating stall which is discerned by the phase lag of pressure fluctuations and also from high speed video images. From Fig.12 it can be seen that the fan with the modified volute design has a broader unstable flow region, at low flow coefficients, compared with the conventionally designed volute.

At the lowest flow coefficient the volutes without a re-circulating port, EA and MA, show a peak amplitude near 10 Hz, This was due to a local periodical stall near the volute tongue accompanied by diffuser rotating stall. This local periodical stall was observed by the image of the nylon tufts that were installed near the diffuser exit. This can be seen in Fig.13, which shows an image of the high speed video near the volute tongue. This is a superimposition of 50 images which were extracted from 1/1000 second exposure time. In this figure the circular images near the volute tongue indicate the local periodical stall. A periodic change of flow direction from

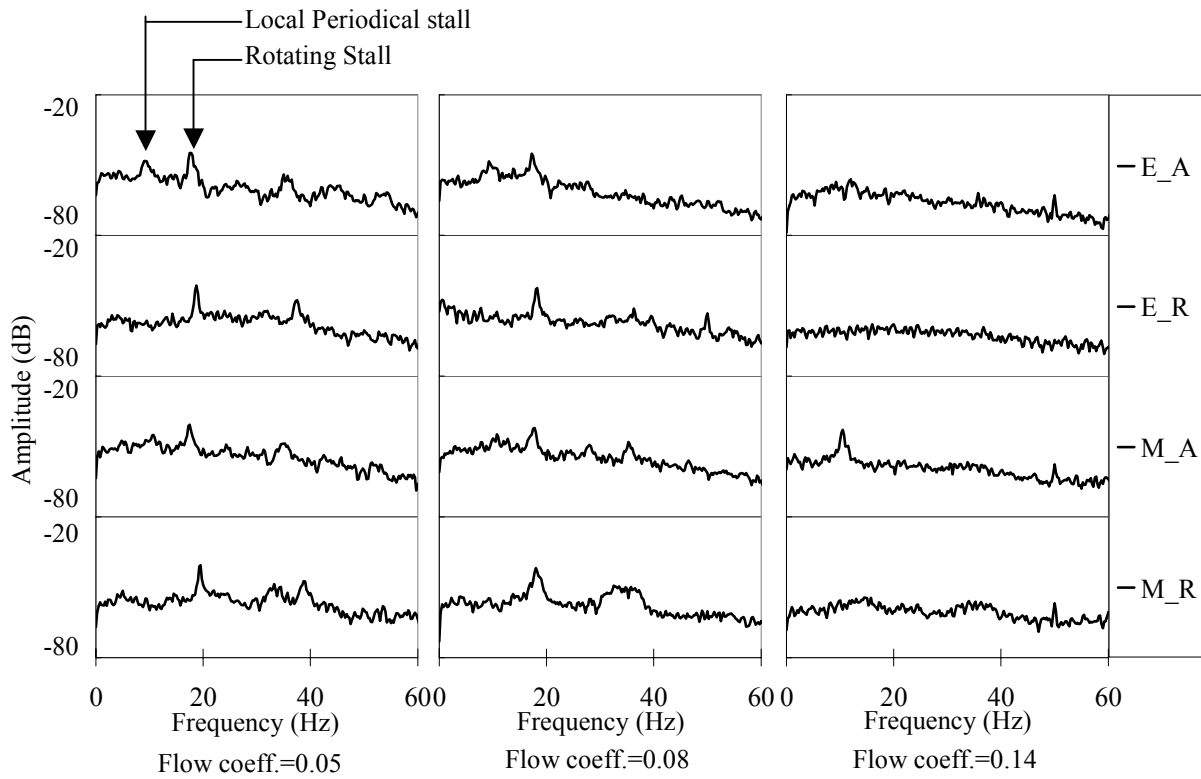


Fig.12 FFT analysis of rotating stall

the volute to the diffuser was caused by diffuser rotating stall; flow passed into the diffuser from the volute passage, upstream of the volute tongue, even though there was no re-circulating port. This local periodic stall has half frequency of diffuser rotating stall. By the change of location of diffuser rotating stall region, by increasing the flow coefficient, this re-circulating flow vanished. This was inferred from the flow pattern just before onset of diffuser rotating stall, Fig.14-a and -b.

The visualized images of rotating stall, at azimuth angles of 45 to 90 degrees, are shown for the 4 volutes in Fig.15. It seems that the increased cross sectional area of volutes MA and MR leads to a flow stagnation near the upstream of the volute passage and this is connected to the reduced of fan performance.

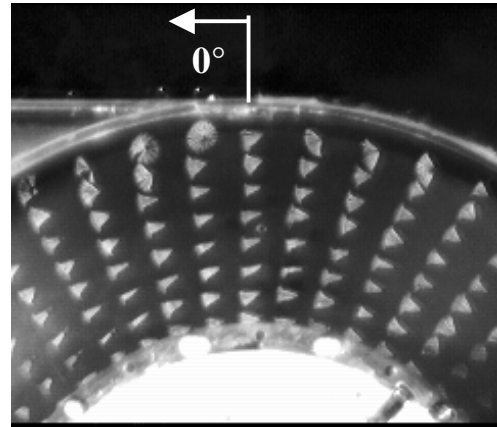


Fig.13 Flow in the diffuser of volute MA (Flow coeff.=0.05)



Fig.14-a Distribution of velocity vector, Component parallel to the diffuser wall (Flow coeff.=0.19)



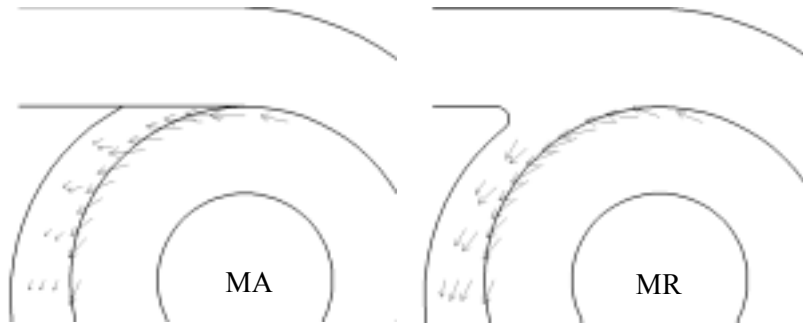


Fig.14-b Distribution of velocity vector, Component parallel to the diffuser wall (Flow coeff.=0.19)

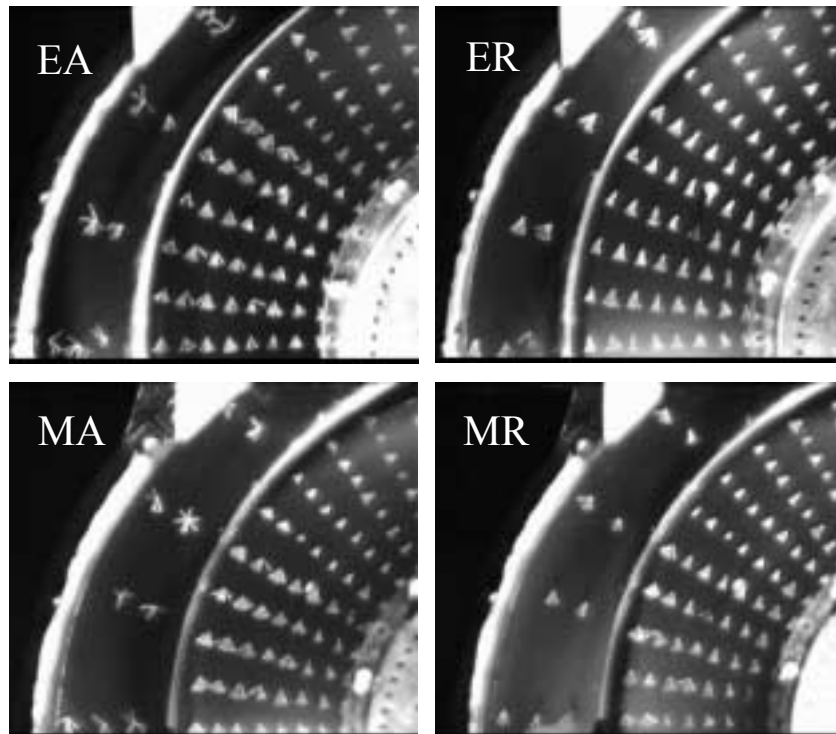


Fig.15 Flow visualization in the volute (Flow coeff.=0.05)

### CONCLUSIONS

Through this study it has been observed that the modified volute designs led to improve performance at moderate and high flow rates, but did not improve the stability at low flow rates. Adoption of a re-circulating flow port improved fan performance for all flow regions. For the volute without a re-circulating flow port, in the low flow region, self sustained re-circulating flow was generated for the resolution of pressure imbalance.

### REFERENCES

- (1) Eck B, "Fans", Pergamon Press, Oxford 1973
- (2) K.Miyanaga et al, "A study of volute tongue and passage design on the performance of centrifugal turbomachines" ,Proc. of the 14<sup>th</sup> Australasian Fluid Mechanics Conference, pp 493-496, 2001
- (3) Yao C F et al, "Study on the scroll of the fan with high efficiency and low noise"(in Chinese), Fluid Engineering 19(7), 2-6,,1991
- (4) Qi D T et al, "A new approach to the design of fan volute profiles" , Proc Instn Mech Engrs v. 210 Pt C of Mech Eng Sci. pp 287-294 1996
- (5) Dillin P et al, "A computational and experimental evaluation of the performance of a centrifugal fan volute", ProcIMechE v.212 ptA 1998